African Journal of Environment and Natural Science Research
Volume 2, Issue 3, 2019 (pp. 62-70)
www.abjournals.org

GEOSPATIAL RISK ASSESSMENT AND MODELLING OF NATURAL HYDROCARBON SEEPAGE IN UGWUEME

Mfoniso A. Enoh[1], Francis I. Okeke[1] and Chukwudi Andy Okereke[2]

[1]Department of Geo-Informatics and Surveying, Faculty of Environmental Studies, University of Nigeria
[2]Department of Surveying and Geo-informatics, Faculty of Environmental Sciences, Imo State University, Owerri Nigeria

ABSTRACT: *The aim of this study is to use geospatial technology to model and access the risks caused by natural occurring hydrocarbon seepage in Ugwueme town, Enugu State Nigeria. To this end, the hydrocarbon seepage hazard and vulnerability model maps of Ugwueme were created and superimposed, by using the ArcGIS 10.5 software to produce the final resultant risk assessment model map. The risk assessment model map was re – classed into four assessment zones as: severe risk, high risk, medium risk and low risk. The result of the study shows that 47.93% and 22.16% of the total area of Ugwueme are classified as severe and high risk areas, due to hydrocarbon seepage while 10.15% and 19.76% are considered as medium and low risk areas respectively. The study concludes that from the final risk assessment model map, Ugwueme is prone to severe risk due to hydrocarbon seepages as more than 70% of the study area is exposed to severe risk and high risks while less than 30% is prone to medium and low risks. Sequel to the findings, the study recommends good land use planning as a vital way to reduce the adverse effects of hydrocarbon seepage in Ugwueme. Thus, town planners and the necessary authorities should adopt an appropriate land use development plan in areas of hydrocarbon seepage within Ugwueme.*

KEYWORDS: Hydrocarbon Seepage, Risk Assessment, Vulnerability, Remote Sensing, Hazard, Nigeria

INTRODUCTION

Hydrocarbon reservoirs in the earth's subsurface often leak (Gluyas and Swarbrick, 2004). This leakage is sequel to abundance oil and gas in the subsurface, and as they pass through impermeable seals, along faults and fractures in rocks and planes of weakness between geological layers, and at high pressure, they form seepages at the earth's surface (Okeke F.I. and Enoh M.A., 2016). The vertical migration of hydrocarbon oil and gas through fractures and along faults in rocks and planes of weakness is known as Chimney effect (Shi et al, 2010). Hydrocarbon oil and gas that seeps into environment can result from natural or man – made processes (Schumacher, 2000). In the natural process, the seepage occurs as a result of pressure differences which forces hydrocarbons to migrate from the subsurface reservoirs to shallow levels and eventually seep to the surface (Schumacher and Abrams, 1996). Several studies have shown that natural hydrocarbon seepage may contribute to hazard, and risk assessment has emerged as a result of worldwide interest in different areas of hazard (Oremland et al, 1987). Risk is considered as a function of the hazard event and the vulnerability of the elements exposed (Birkmann, 2007). Brooks (2003), is of the option that risk is the probability of occurrence of risk event, which triggers undesirable outcomes. Thus, the magnitude of risk depends on its probability and potential consequences. Hydrocarbon seepage risk assessment is a result of the combination of two components – Hazard and vulnerability (Ouma and Tateishi, 2014), which can also be a product of three major elements: exposure to hazards, the frequency or severity of the hazard and the vulnerability (Birkmann, 2007). While hazard is the probability of occurrence of a damaging phenomenon, vulnerability is the characteristics of a person or group of persons and their situation that influences their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (Blaikie et al 2004). White et al (2005), was of the opinion that in the context of hazards, vulnerability can be seen to have two basic elements: exposure and susceptibility to harm. While the researchers noted that exposure is determined by where and how people live and work relative to a hazard, susceptibility takes into account those social, economic, political, psychological and environmental variables that intervene in producing different impact among people with similar levels of exposure. Several studies have shown that geospatial technology is applicable in various aspect of risk assessment. Granger et al (1999) used GIS to model the spatial relationship between vulnerability and hazard to study the risk by Cairs in Australia to multi – hazard phenomenon. Their study identified and mapped the main factors affecting the community vulnerability with the following datasets: buildings, mobility power, water supply, logistics support, health, wealth/economic resources protection, languages and ethnicity, religion, education and community service. Udoh et al (2011) mapped the oil spill in the coastal areas of Akwa Ibom State Nigeria using GIS based risk assessment techniques. The resulting risk layer of their study, was classed into four risk zones of very high, high, moderate and marginal risk. Thumerer et al (2000) developed a GIS based risk assessment model, where he combined oceanographic and climatic data with data on sea defences, elevation values and patterns of land use. Risk assessment now integrates multi – criteria technique with geospatial technology in handling environmental issues and hazard, and geospatial technology has an added advantage. Thus, researchers such as Jorin et al (2001) and Pramojanee et al (1997) effectively utilized risk assessment and geospatial technology in handling land suitability assessment and for flood vulnerability mapping. Syed T. T. et al (2018) monitored and mapped oil spill and gas leakage in vulnerability zones in Pakistan using GIS based risk assessment. Their study shows that after the evaluation of hazard and vulnerability zones in Pakistan, it is now imperative to study the risks involved sequel to oil and gas leakages. The overall aim of this study is to examine the ways in which geospatial techniques can be effectively utilized in risk assessment and modelling of natural hydrocarbon seepage in Ugwueme.

The Study Area - Ugwueme

The study was carried out in Ugwueme. Ugwueme is a small community in Awgu Local Government of Enugu State, Nigeria. Ugwueme is bound by Latitude 60^{0}0'00''N and 60^{0}03'00''N and Longitude 70^{0}24'00''E and 702800E of geographical co – ordinates. According to the National Population Commission (2006), Ugwueme has an estimate population of 13,000 people. The community is accessible through a network of un – tarred road, laterite graded roads and several footpaths through Awgu market, Nkwe and Onoli (Okeke F.I. and Enoh M.A.) The people of Ugwueme are mostly subsistence farmers, who cultivate food and cash crops such as yam, cassava, cocoyam and maize, cashew, oil palm and banana and raise livestock such as sheep, local breeds of chicken and the West African dwarf goats (Onyeabor, 2013). Within Ugwueme, the soil is mainly Ferralitic, which is known as Red Earth. The nature of the red earth soil, makes the area only suitable for the cultivation of cash crops, as it is poorly drained. Ugwueme often experiences heavy rainfall during the rainy season, with a record of 1,800 mm. This heavy rainfall promotes high infiltration rate and which is believed to cause the oil bitumen to be flushed out from the tar sand as heavy tarry and sticky crude. This assertion is supported by the frequency reports of oil and gas which is associated with seepage in Ugwueme during and immediately after each rainy season (Okeke H. C. 2006).

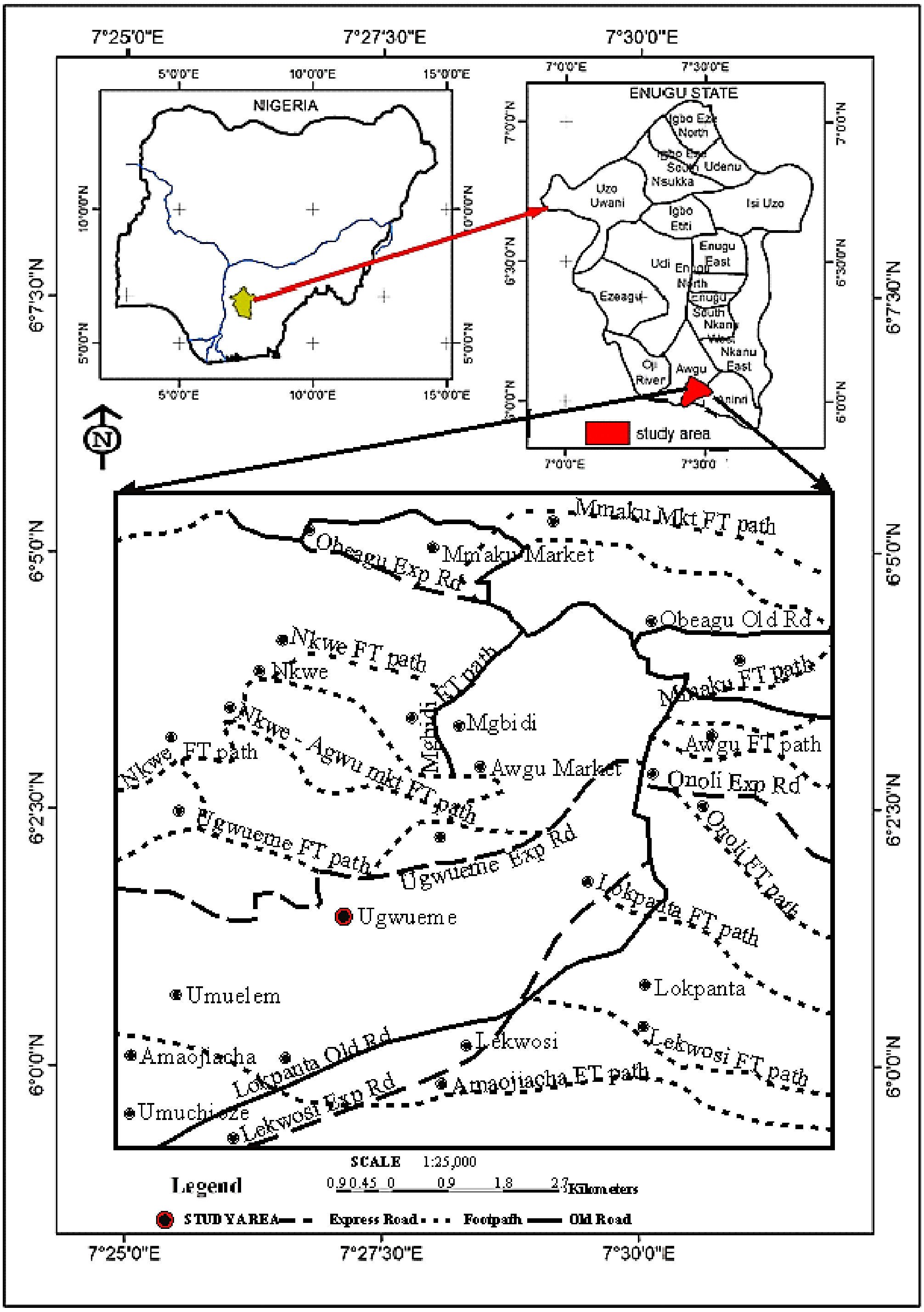

Figure 1: Accessibility Map of Ugwueme Community, Nigeria

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METHODOLOGY

To create a risk assessment model map for the study, a qualitative map is first generate by combining several factor maps, then a vulnerability map is made. The combination of hazard and vulnerability model maps result in a risk assessment model map.

Hazard Parameters and Modeling

To model hazard surface in Ugwueme, two components are considered: Hazard parameters and impedance surface. These components are used as input to produce the hazard surface in the cost distance tool in Arc map 10.5 software's spatial analyst extension through the following sequences: Toolboxes – System Toolboxes – Spatial Analyst Tools – Distance – Cost Distance. This tool analyzes the least accumulative cost distance for each cell to the nearest sources, which depends on a cost surface. Hazard in this study was identified from the sources of seeps in Ugwueme which includes: oil seepage = 1, gas seepage = 2, mud volcanoes = 3, tars = 4. In this study, impedance surfaces were modeled by the following layers: physiographic and geomorphologic units, hydrologic units and slope surface. Arc map 10.5 software has a cost distance spatial analyst module that aids one to model the movements from a source across impedance surface. Hence, using each hazard source. Hazard surfaces were modeled to reflect the impact as oil and gas moves over each impedance surface. A final hazard surface was created by prioritizing the hazards for the various components, combining the components and finally zoning the resultant surface into hazard classes.

Hydrocarbon Seepage Vulnerability Model

Vulnerability is the measure of how the elements in a landscape would be at risk and then become damaged if they experience same level of hazard. Vulnerability is multidimensional, and each element will be affected differently by hazards. To create Vulnerability model map for the study, the following parameters, produced from ASTER DEM were utilized. Slope, Aspect, flow accumulator and flow direction. In the study, ASTER DEM was imported into the ArcGIS 10.5 software, using the add button and where all the sinks were filled for the creation of the flow direction grid model. Filling of sink is necessary, as sinks prevents flow algorithms to follow a complete flow path to the watershed's outlet. The flow accumulator was created, using the flow direction grid model. The slope map of Ugwueme was extracted from the ASTER DEM using ArcGIS 10.5 software and was calculated using the spatial analyst tool. Similarly, the aspect of the study area was extracted from ASTER DEM by utilizing the spatial analyst and 3D analyst tools in ArcGIS 10.5 software. Weighted Overlay Analysis was then used to generate the final hydrocarbon seepage Vulnerability model.

Risk Surface Modeling and Zonation

To create the final risk surface in the study, the hazard and vulnerability layers were combined equally (50% each) using the single output map algebra of Arc map. The resultant map was re-classed and zoned into Four Risk Zones: Severe Risk, High Risk, Medium Risk, And, Low Risk.

RESULTS OF THE STUDY

Vulnerability Modeling of Ugwueme.

Figure 2 shows the vulnerability model map of Ugwueme. The map is classified into five categories of vulnerability, the very low to low vulnerability, the moderate vulnerability, high vulnerability and very high vulnerability for hydrocarbon seepage to spread within Ugwueme. Visualizing the map, we see that the central part towards the eastern part of Ugwueme is highly vulnerable to hydrocarbon seepage as compared to the southern and northern parts that are less vulnerable.

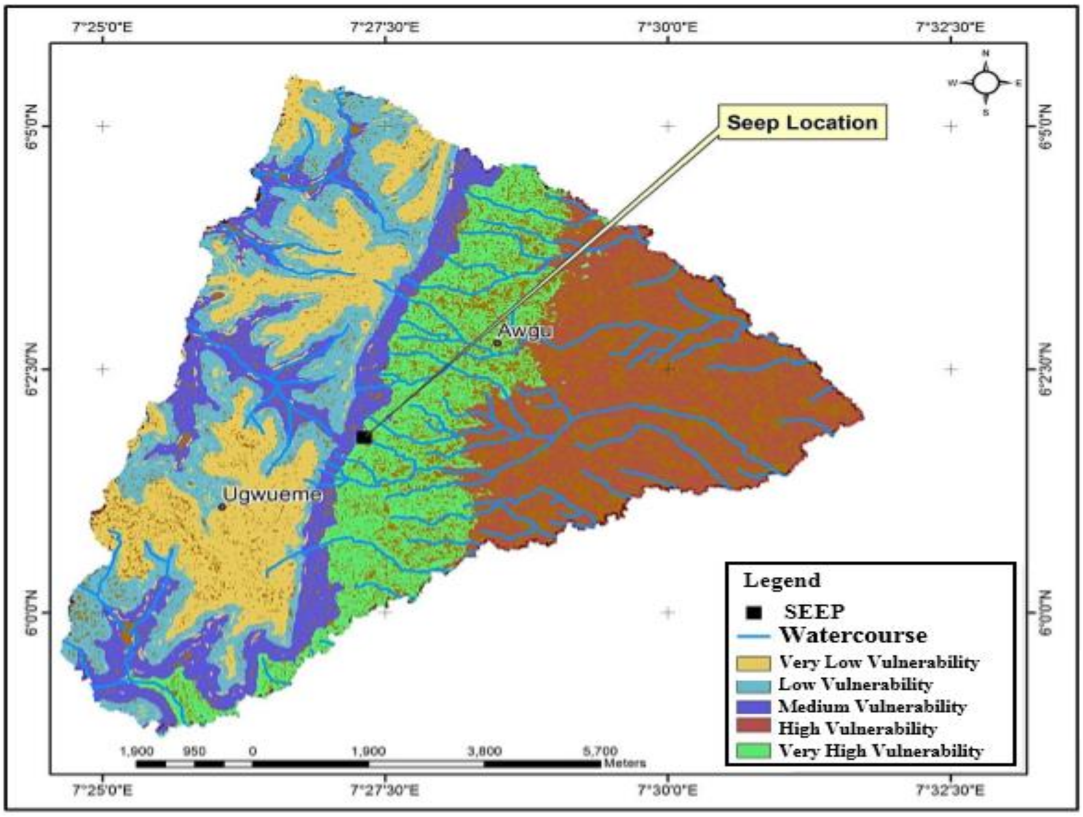

Figure 2: Hydrocarbon Seepage Vulnerability Model Map of Ugwueme

Table 1: Hydrocarbon Seepage Vulnerability Zone within Ugwueme

S/N	Vulnerability Zone	Area (sq. km)	Percentage (%)
1	Very High Vulnerability	93.125	19.736
2	High Vulnerability	196.215	41.583
3	Medium Vulnerability	55.895	11.846
4	Low Vulnerability	42.458	8.998
5	Very Low Vulnerability	84.172	17.838
	Total	**471.865**	**100.000**

From table 1, we see that areas of very high vulnerability to hydrocarbon seepage amount to 93.125km^2 accounting for 19.74%, while areas of high vulnerability hydrocarbon seepage amount to 196.215km^2 and yield 41.538%. Areas of medium vulnerability owing to seepage occupies an area of 55.895km^2 and account for 11.85%, while areas of low and very low vulnerability sequel to hydrocarbon seepage occupy an area of 42.46km^2 and 84.172km^2 and accounting for 9.00% and 17.84% respectively of the total area of Ugwueme.

Hydrocarbon Seepage Hazard Modeling of Ugwueme

Figure 3 shows the hydrocarbon seepage hazard model of Ugwueme. The model map is classified into five categories as very low seepage hazard to very high seepage hazard for seepage to spread within the study area. The high and very high hazard areas of hydrocarbon seepages refer to the areas where seepages can spread easily. Progressively from the western to the eastern area of Ugwueme, we see that seepage decreases and becomes very low while becoming very high at the northern and southern parts of the study area. The very low risk and low hazard owing to hydrocarbon seepages are locations where chances of hydrocarbon seepage are about zero. For the moderate hazard, the chances are low as well.

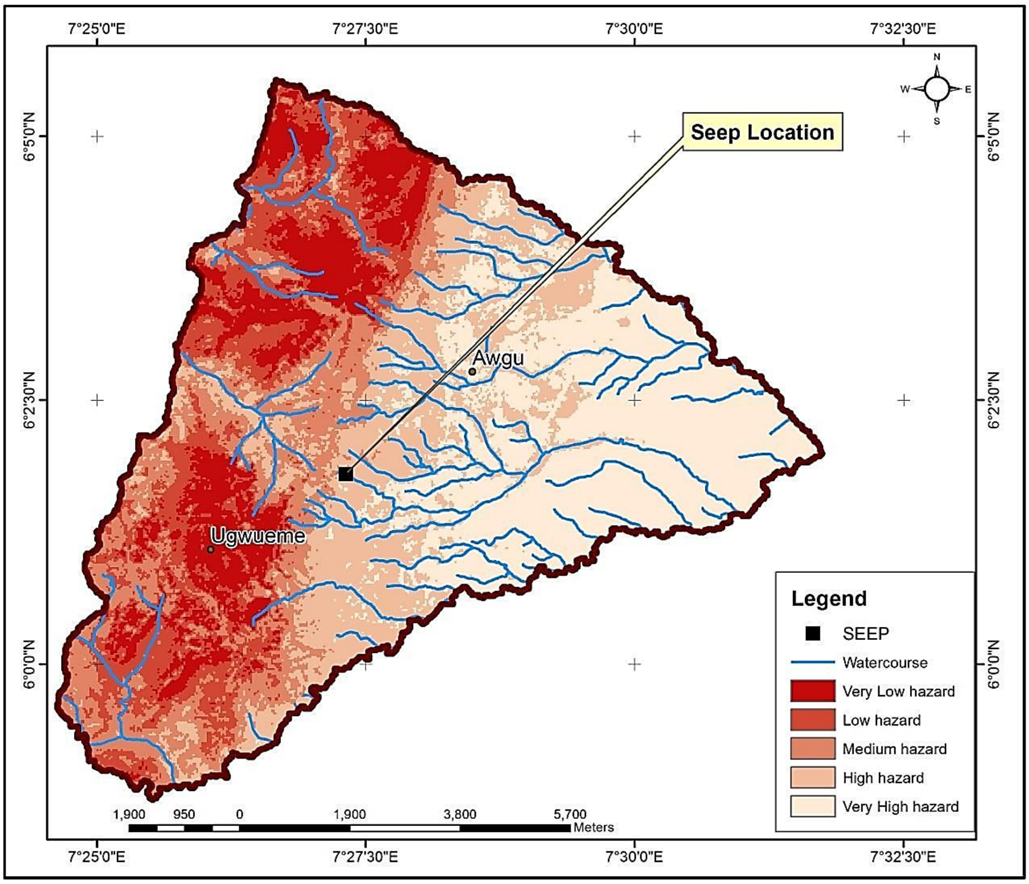

Figure 3: Hydrocarbon Seepage Hazard Model Map of Ugwueme

Table 2: Hydrocarbon Seepage Hazard distribution within Ugwueme

S/N	Hazard Zone	Area (sq. km)	Percentage (%)
1	Very High hazard	187.284	39.690
2	High hazard	72.292	15.320
3	Medium hazard	98.755	20.929
4	Low hazard	76.378	16.186
5	Very Low hazard	37.156	7.874
	Total	**471.865**	**100.000**

From table 2, we see that within Ugwueme, areas of very high and high hazard, owing to the flow of seepage are 187.284km^2 (39.69%) and 72.292km^2 (15.320%) respectively while areas of moderate and low hazard amount to 98.755km^2 (20.93%) and 76.378km^2 (16.19%) respectively. Very low hazard occupies an area of 37.156km^2 representing 7.87% of the entire hazard zone. From our analysis, we see that Ugwueme is prone to very high hazard due to the wide spread of hydrocarbon seepage.

Hydrocarbon Seepage Risk Assessment Model of Vegetation

Figure 4 shows the hydrocarbon seepage risk assessment model of Ugwueme. The model is grouped into four classes as: severe risk, high risk, medium risk and low risk assessment model. Within the eastern part of Ugwueme, hydrocarbon seepage assessment risk is severe as compare to other parts. At the central part, seepage risk assessment is high, but it is medium and low at the southern and northern part of Ugwueme.

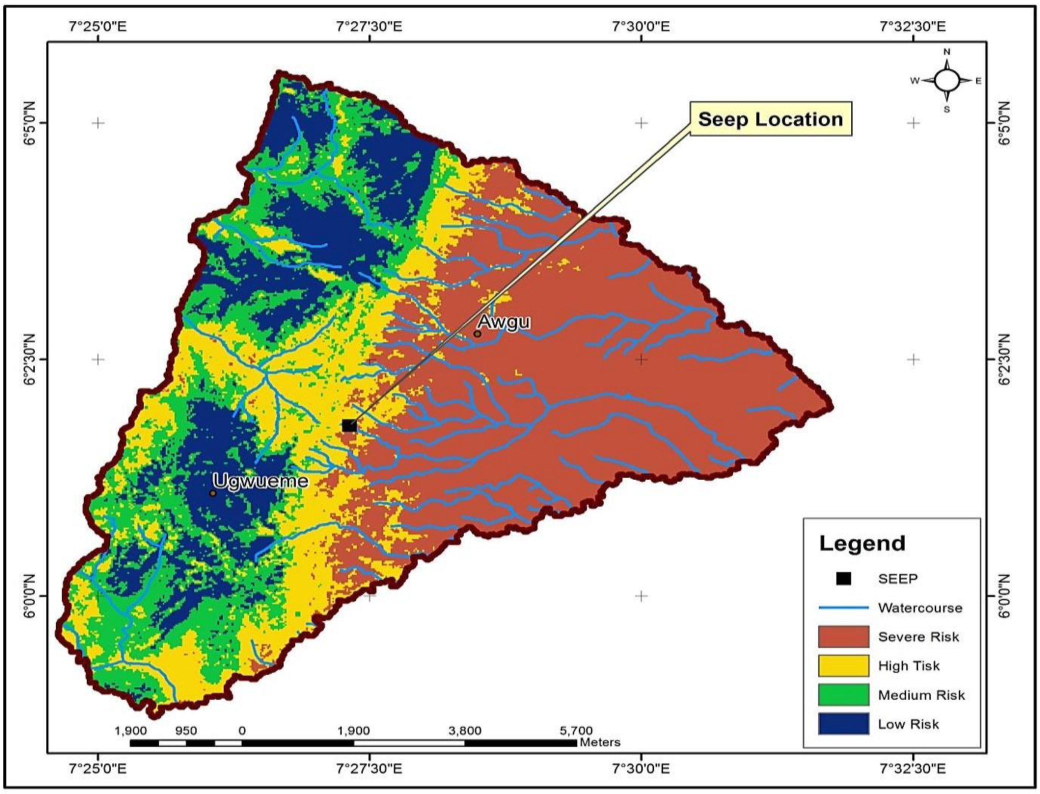

Figure 4: Hydrocarbon Seepage Surface Risk Zone Model Map within Ugwueme

Table 3: Hydrocarbon Seepage Risk Assessment distribution within Ugwueme

S/N	Risk Zone	Area (sq.km)	Percentage (%)
1	Severe Risk	226.147	47.930
2	High Risk	104.532	22.155
3	Medium Risk	47.899	10.152
4	Low Risk	93.253	19.764
	Total	**471.831**	**100.000**

The result shows that within Ugwueme, an area of 226.147km^2 (47.93%) is located in severe risk area while 104.532km^2 (22.16%) is located in high risk zone sequel to hydrocarbon seepage. In the medium and low risk zone, an area of 47.899km^2 (10.15%) and 93.253km^2 (19.76%) respectively are represented in Ugwueme, due to hydrocarbon seepage. The statistics show that Ugwueme is prone to severe risk as a result of hydrocarbon seepage.

CONCLUSION

The study shows that geospatial technology is an important tool in modelling the risk assessment due to natural occurring hydrocarbon seepage. Using this tool, the result of the study shows that Ugwueme is prone to high risk due to natural hydrocarbon seepage, as more than 70% of the zone is exposed to severe and high risk while less than 30% is prone to medium and low risk. From the findings, the study recommends good land use planning as a vital way to reduce the adverse effects of hydrocarbon seepage in Ugwueme. Sequel to this findings, individuals, town planners and the authorities should adopt an appropriate land use plan in areas of hydrocarbon seepage within the study area.

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